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AEROSOL BEHAVIOR IN HIGH PRESSURE ENVIRONMENTS

Robert A. Gussman, et al

Bolt Beranek and Newman, Incorporated
Cambridge, Massachusetts

28 February 1970

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Report No. 1894

AEROSOL BEHAVIOR IN HIGH PRESSURE ENVIRONMENTS — Second Annual Report

Robert A. Gussman
Anthony M. Sacco

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Sponsored by:

Department of the Navy
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TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

LIST OF TABLES

Section 1: INTRODUCTION

The continuing goal of this project has been to investigate hazards that might arise from the presence of aerosols in a high pressure environment. We have dealt solely with the specific environment considered for saturation diving vehicles to depths of 1,000 ft. The first year this study included theoretical evaluations of the physical properties of the atmosphere, variations in aerosol behavior due to the pressure and composition of the atmosphere, considerations of aerosol formation, pressure and composition effects on various air cleaning mechanisms, and a first order experiment on electrostatic precipitation. Additionally, during the first year a computer model of pulmonary deposition was constructed to examine the effects of atmosphere pressure and composition upon aerosol deposition in the lung. At the conclusion of this second year, specific investigations have been completed on the effects of increasing pressure in the environment on the generation of particles from heated surfaces. A much more detailed model of the lung using the best available information has been constructed and evaluated. These two items have been presented in a special technical report[1] and will not be reinterated here.

Our initial review of filtration mechanisms indicated a potential decay in collection efficiency as pressure increases. Accordingly, we are in the process of evaluating a potentially applicable filter media (provided by NRL). A complete set of theoretical calculations have been detailed and are presented in this report as well as plans for the experimental apparatus which is under construction. The actual evaluation of the media and filtration process will be carried on during the forthcoming year.

The literature review phase of the project has continued and our findings generally reflect those of the preceding year in that no information bearing directly on this project has been uncovered. The papers and publications reviewed are listed without further comment in an appended bibliography.

Technical papers are under active preparation on the subject of pulmonary deposition and aerosol behavior within an enclosed vessel. These will be submitted for publication pending their completion and appropriate contract approvals.

Section 2: FILTRATION

Section 5.0 of the First Annual Report[2] discussed six mechanisms possibly active in the filtration of particulates by fibrous media and how the process would be effected by the increasing pressure and changing composition of the environment. The six mechanisms as defined by Pich[3] are:

(1) diffusional deposition,

(2) direct interception,

(3) inertial deposition,

(4) electrostatic deposition,

(5) gravitational deposition, and

(6) deposition influenced by molecular (van der Waals') forces.

Pich's review of aerosol filtration processes in the book edited by Davies[3] is extremely comprehensive and detailed. It permitted an examination of each of the factors and an approximation of the effects of the high pressure environment. Because our review of the submarine literature[2] and experiments on aerosol formation from heated surfaces[1] indicated a rather fine structure to be expected in any aerosol distribution existing in the environment, we have elected to base our actual filtration studies on the diffusion mechanism only. The particle size of interest to this study is less than 0.1μ and it is expected that only this mechanism will be active (with the possible exception of electrostatics). According to the method and suggestions of Pich[3] we have briefly examined the characteristic parameters (N) for impaction, direct interception and diffusion for further assurance that major mechanisms other than diffusion would be negligible in this configuration. This consideration involves establishing the media to be used, the characteristics of which are given in Table 1. The characteristic parameter for direct interception (N_R) is given as:

Table 1. Characteristics of Actual "Absolute" Type Filter Media to be Theoretically and Experimentally Considered*

Name:	All glass fiber media, non-waterproof #475	Area Density:	9.46×10^{-3} g/cm^2
Fiber Diameter:	1) Surface Volume Dia. = 0.64μ 2) Number Diameter = 0.31μ	Packing Density:	0.205 g/cm^3
Thickness (L):	0.046 cm	Solids Fraction (β):	0.0816

*All data furnished by NRL.

Table 2. Extreme Values of Characteristic Filtration Parameters for 0.01μ and 0.1μ Aerosols.

Filtration Parameter	Impaction N_I	Direct Interception N_R	Diffusion N_D
	$\rho_p = 7.1$ (Cr)		
Smallest Value	1.75×10^{-4} $\begin{cases} P = 500 \text{ psia} \\ d_p = 0.01\mu \\ d_f = 0.34\mu \end{cases}$	1.56×10^{-2} $\begin{cases} d_p = 0.01\mu \\ d_f = 0.64\mu \end{cases}$	1.5×10^{-2} $\begin{cases} P = 500 \text{ psia} \\ d_p = 0.1\mu \\ d_f = 0.64\mu \end{cases}$
Largest Value	1.1×10^{-1} $\begin{cases} P = 10 \text{ psia} \\ d_p = 0.1\mu \\ d_f = 0.31\mu \end{cases}$	3.21×10^{-1} $\begin{cases} d_p = 0.1\mu \\ d_f = 0.31\mu \end{cases}$	19.2 $\begin{cases} P = 10 \text{ psia} \\ d_p = 0.01\mu \\ d_f = 0.31\mu \end{cases}$

$$N_R = \frac{d_p}{d_f} \qquad (1)$$

where:

d_p = particle diameter

d_f = fiber diameter

The parameter will have a minimum value of 1.5×10^{-2} for 0.1μ particles with a fiber diameter of 0.64μ. The largest possible value is 0.32 for a particle diameter of 0.1μ and a fiber diameter of 0.31μ. The parameter as stated is uneffected by pressure.

The impaction parameter is given as:

$$N_I = \frac{v\,V}{g\,d_f} \qquad (2)$$

where:

v = sedimentation velocity

V = gas stream velocity

g = gravitational constant.

The smallest value of the impaction parameter will be 2.5×10^{-5} for 0.01μ particles and 0.64μ fibers at 500 psia. Also at 500 psia, 0.1μ particles and 0.31μ fibers yield a parameter value of 2.5×10^{-3}. Both of these values are substantially below those for direct interception and this mechanism is of no interest for the particle size in question.

The descriptive parameter for diffusion is simply stated as the inverse of the Peclet (P_e) number:

$$N_D = \frac{1}{P_e} = \frac{D}{V\, d_f} \tag{3}$$

where:

D = diffusion coefficient corrected for slip.

N_D has a minimum value of 1.5×10^{-2} at 500 psi for a particle diameter of 0.1μ and a fiber diameter of 0.64μ. At 10 psi where the particles will have a maximum mobility the parameter has a value of 19.2 for a 0.01μ particle and a 0.31μ fiber. Note that the largest diffusion parameter value dominates the largest direct interception value but the two smallest values for both diffusion and direct interception are equal. Nevertheless, the direct interception low value is for a 0.01μ particle and the effects of diffusion for that particle size will definitely be the predominating ones. The basis for these conclusions are reinterated in Table 2.

There are at least nine equations[3] which describe diffusional deposition of particles on a fiber. For purposes of this study, considering the flow regime and Knudsen number involved, we have selected as being most applicable the equation independently developed by both Fuchs and Pich[3] which may be stated as:

$$E_D = \frac{2.86}{Y^{1/3}\, P_e^{2/3}} \left(1 + \frac{0.388\, \chi\, P_e^{1/3}}{Y^{1/3}}\right) \tag{4}$$

where:

$$Y = -\frac{1}{2} \ln \beta - C + 1.996\, \chi(-1/2 \ln \beta - C + 1/2)$$

where:

χ = fiber Knudsen number $\frac{\lambda}{d_f}$

λ = mean free path of the gas molecules

β = volume fraction of fibers

C = a constant 0.5 or 0.75*

This equation is derived from considerations of the Kuwabara-Happel velocity field surrounding the fiber. The range of Knudsen numbers for a variety of fiber diameters over the pressure regime involved is plotted in Figure 1. When the Knudsen number is small (10^{-3} to 0.25) then equ. no. (4) is utilized. When slip may be neglected ($\chi \rightarrow 0$) the expression for Y reduces to $Y = -1/2 \ln \beta - C$ and the whole equation reduces to:

$$E_D = \frac{2.86\, P_e^{-2/3}}{(-1/2 \ln \beta - C)^{1/3}} \qquad (5)$$

Equations (1) and (2) characterize only the diffusional deposition efficiency for a single fiber. They do, however, because they are derived from considerations of the Kuwabara-Happel field, include the interference effect of other fibers.

*NOTE: There is no physical basis for choice but rather, different authors[3] arriving at almost the same equation. We have elected to use 0.75.

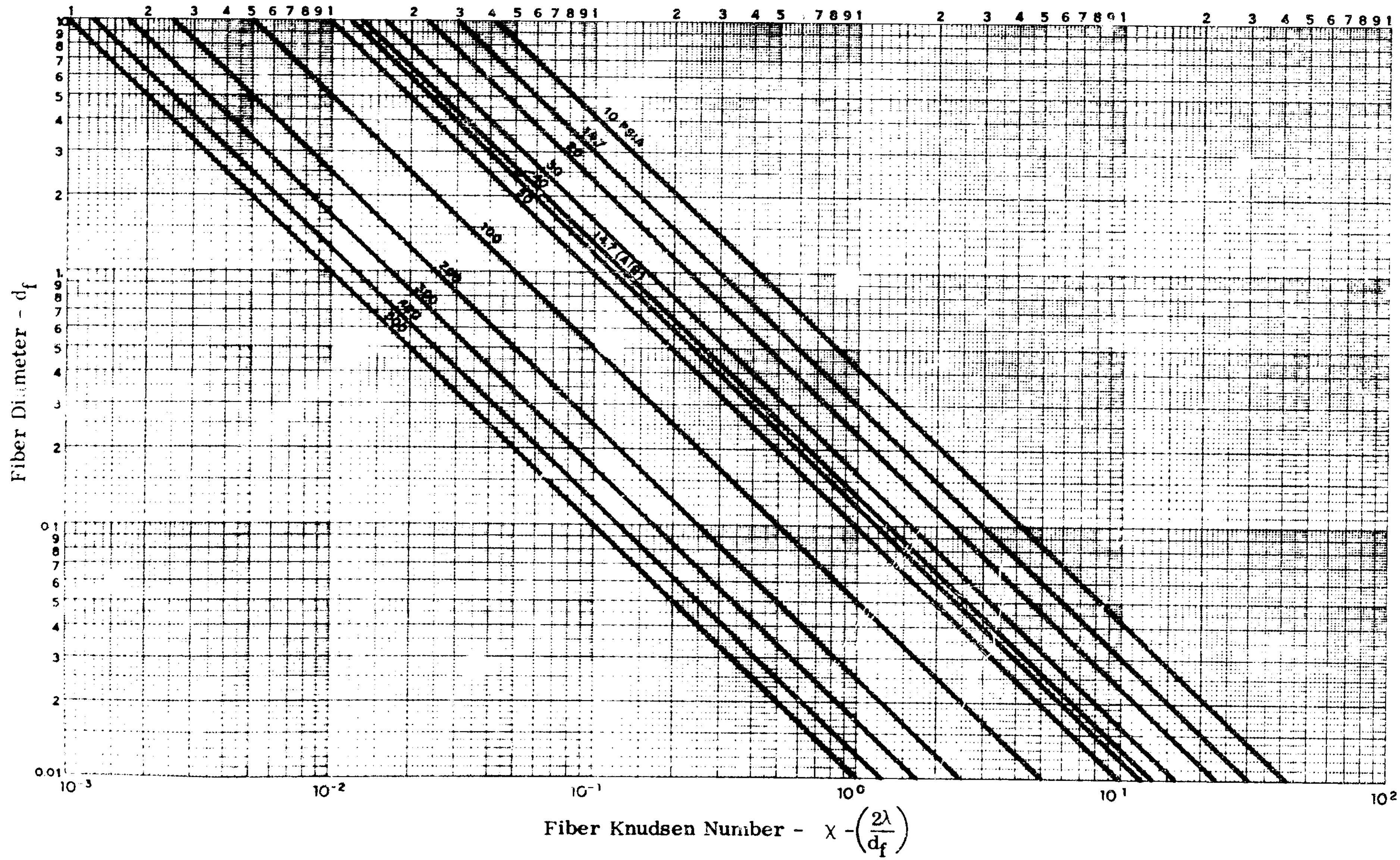

Figure 1. Fiber Knudsen Number vs Fiber Diameter at Various Pressures of an Oxygen-Helium Atmosphere. (PO_2 = 160 mm Hg; T = 20°C).

In order to determine the total filter efficiency the following equation is utilized[3]

$$E_T = 1 - e^{\alpha} \tag{6}$$

where:

$$\alpha = \frac{4}{\pi} \cdot E_D \cdot \frac{\beta}{1 - \beta} \cdot \frac{L}{d_f}$$

where:

α = coefficient of adsorption through the filter

L = thickness of filter material

Equation nos. (4) and (6) have been written into a computer program and several runs have been made using the media specified in Table 1. Both the surface-volume fiber diameter (0.64μ) and the count fiber diameter (0.31μ) have been considered as it is not clear which of these numbers (or possibly the intervening descriptors) is truly applicable to diffusional filtration mechanisms. The particle diameters considered are 0.1μ and 0.01μ. These sizes essentially bracket those found in the experiment on the generation of particles from heated surfaces.[1] The data from these initial experiments is presented again in Figure 2. An additional set of computer calculations were made utilizing actual count median diameter (M_g) sizes as represented by the left line in Figure 2. The results of these calculations are summarized in Table 3 and plotted in Figure 3. It should be noted that the claculations, as made, are in some areas outside the limits of eqn. (4) in that some of the Knudsen numbers are too large (Figure 1) and some of the Peclet numbers are greater than 1 which is an upper limit for the application of Eqn. (4). Further theoretical calculations have not been carried out to reduce the Knudsen number and Peclet number problem for two reasons. First, it is highly probable that an additional calculation covering the

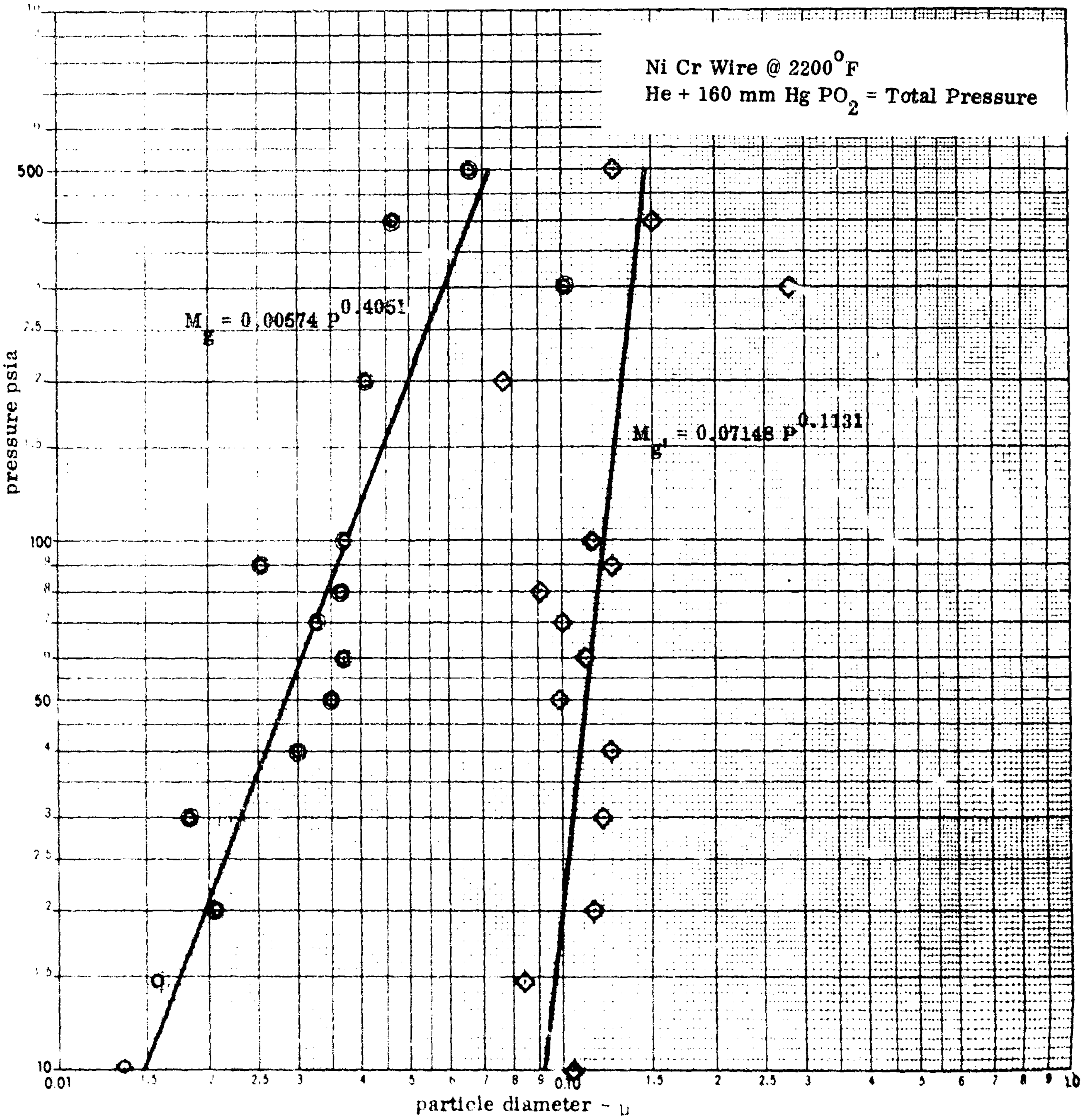

Figure 2. Count (M_g) and Mass ($M_{g'}$) Median Diameters vs Pressure (Ref. 1).

Table 3. Filter Efficiency Calculations for the Diffusional Mechanism in a Helium-Oxygen Environment (PO_2 = 160 mm Hg).* (V = 2.46 cm/sec).

	Pressure psia	Peclet Number	E_D	E_T
d_f = 0.31μ	10.0	.1138	9.68	1.00000000
d_p = actual	14.7	.2117	6.99	1.00000000
(Fig. 2)	20.0	.3631	5.21	1.00000000
	30.0	.7361	3.61	1.00000000
	40.0	1.1732	2.72	1.00000000
	50.0	1.6226	2.26	1.00000000
	100.0	4.5665	1.23	1.00000000
	200.0	10.5917	.73	.99999937
	300.0	15.5633	.57	.99995095
	400.0	18.1571	.52	.99969000
	500.0	23.1091	.44	.99810884
d_f = 0.64μ	10.0	.2359	6.96	1.00000000
d_p = actual	14.7	.4373	4.94	1.00000000
(Fig. 2)	20.0	.7497	3.63	1.00000000
	30.0	1.4578	2.47	1.00000000
	40.0	2.4222	1.83	1.00000000
	50.0	3.3498	1.50	.99999999
	100.0	9.4275	.79	.99980303
	200.0	21.8667	.46	.98700379
	300.0	32.1306	.36	.95001472
	400.0	37.4857	.32	.91206253
	500.0	47.7091	.28	.84774230
d_f = 0.31μ	10.0	.0522	15.72	1.00000000
d_p = 0.01μ	14.7	.0713	13.83	1.00000000
(Fig. 2)	20.0	.0937	12.21	1.00000000
	30.0	.1352	10.27	1.00000000
	40.0	.1769	9.05	1.00000000
	50.0	.2179	8.11	1.00000000
	100.0	.4190	5.72	1.00000000
	200.0	.7782	4.00	1.00000000
	300.0	1.0802	3.28	1.00000000
	400.0	1.3309	2.89	1.00000000
	500.0	1.5406	2.64	1.00000000

*See Equation 1, Table 1, Figure 1.

Table 3 - continued

	Pressure psia	Peclet Number	E_D	E_T
$d_f = 0.64\mu$	10.0	.1078	11.39	1.00000000
	14.7	.1471	9.87	1.00000000
$d_p = 0.01\mu$	20.0	.1934	8.62	1.00000000
	30.0	.2791	7.13	1.00000000
	40.0	.3653	6.17	1.00000000
	50.0	.4498	5.48	1.00000000
	100.0	.8651	3.74	1.00000000
	200.0	1.6065	2.55	1.00000000
	300.0	2.2300	2.07	.99999997
	400.0	2.7476	1.81	.99999881
	500.0	3.1806	1.65	.99998725
$d_f = 0.31\mu$	10.0	5.0171	1.06	1.00000000
	14.7	6.6895	.91	1.00000000
$d_p = 0.1\mu$	20.0	8.4452	.80	1.00000000
	30.0	11.3482	.68	1.00000000
	40.0	13.7653	.61	1.00000000
	50.0	15.7562	.56	.99999959
	100.0	22.1043	.46	.99996423
	200.0	27.3333	.40	.99958687
	300.0	29.4440	.38	.99860651
	400.0	30.6265	.37	.99682542
	500.0	31.3827	.36	.99411576
$d_f = 0.64\mu$	10.0	10.3579	.72	1.00000000
	14.7	13.8105	.61	1.00000000
$d_p = 0.1\mu$	20.0	17.4352	.53	.99999878
	30.0	23.4286	.45	.99979453
	40.0	28.4188	.39	.99751159
	50.0	32.5289	.36	.98968523
	100.0	45.6348	.29	.95597108
	200.0	56.4301	.25	.90461374
	300.0	60.7876	.24	.86142486
	400.0	63.2259	.23	.82192288
	500.0	64.7901	.23	.78543258

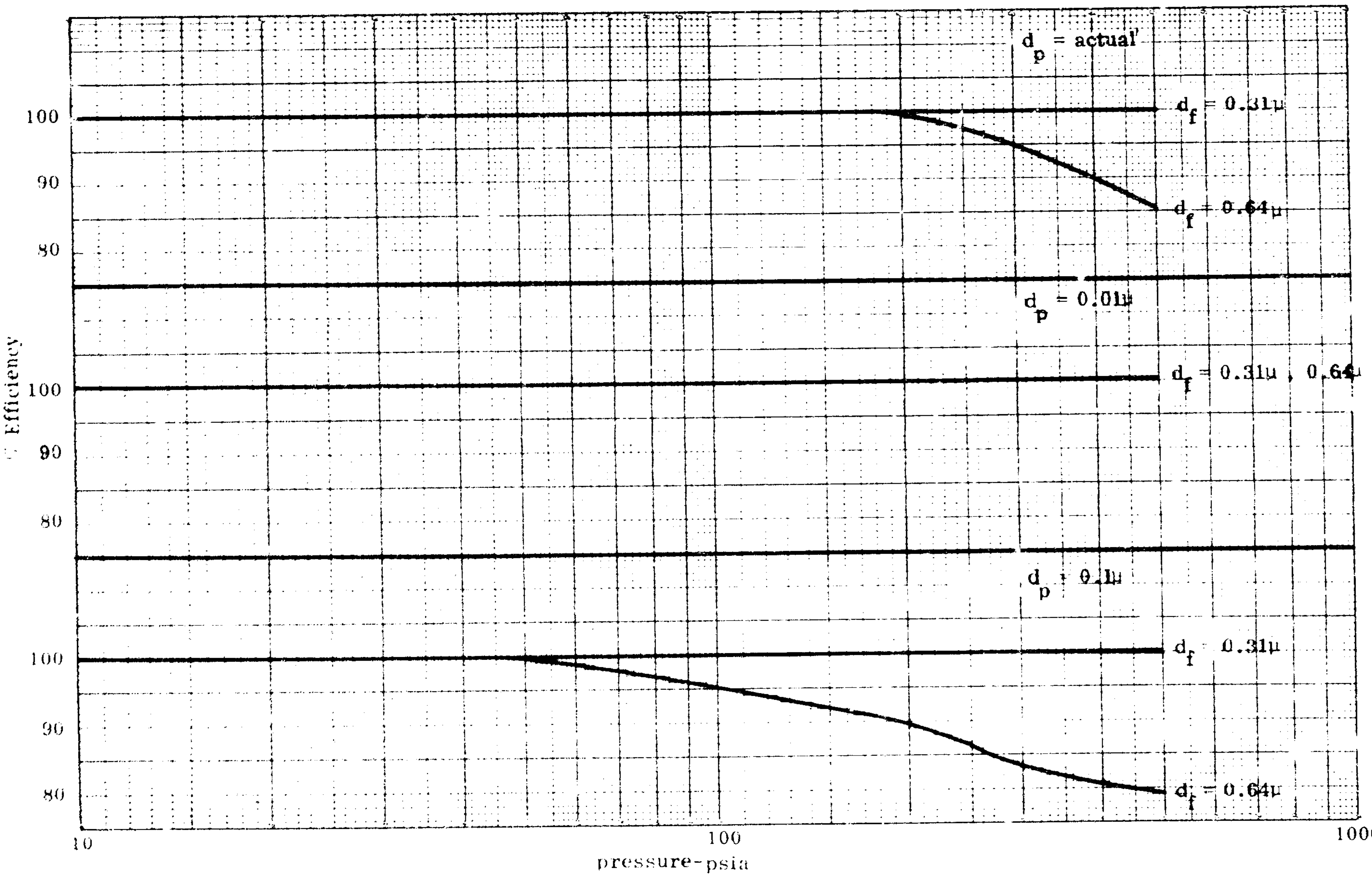

Figure 3. Calculated Filter Efficiency vs Pressure for the Diffusional Mechanism in a He-O_2 Environment.*

*See Table 3.

areas in question will not yield figures matching the balance of the calculations and secondly, there is a wide number of equations to pick from in the high Knudsen number range but only one in the low Peclet number range. Therefore, it was felt that further calculation would only confuse the presentation and since the difficulty lies in the lower pressure ranges considered, the theoretical results would be of little interest or usefulness to the project.

It is planned that in the conduct of an actual experiment Eqn. No. (4) will be utilized to determine a theoretical curve with the insertion of one item of real data from the experiments, namely, the observed upstream particle size. In this way we can determine whether the observed efficiency is solely by the diffusional mechanism or is being effected by additional factors.

Section 2.1 Experimental Apparatus

The experimental apparatus for any filtration experiment generally consists of a source of aerosol,an upstream sampling apparatus, the filter holder, and a downstream sampling apparatus. In view of our desire to sample at pressures up to 500 psia, several additional factors have to be considered. The gas mixture to be used for all experiments is helium and oxygen in the proportions considered throughout all our previous work, namely 160 mm mercury Hg partial pressure oxygen and the balance to the total pressure helium. These mixtures were very easy to achieve in closed static vessels as previously reported,[1,2] but our initial engineering considerations for a flow system indicated that dynamic mixing apparatus would be quite expensive to construct relative to the costs of the balance of the work. Therefore, we have elected to use premixed and analyzed tanks of gas. Four pressures have been selected at which the work will be carried out. These are: 50, 100, 300, and

500 psia. The equipment has been designed in detail for this experiment and is schematically shown in Figure 4. Flow control will be achieved by initially setting the high pressure tank regulator to the desired pressure level. The gas will be allowed to flow through the entire length of the system and exit through a needle valve which will permit the reduction of pressure back to ambient conditions. The quantity of flow will be monitored by a rotameter calibrated for the gas being used. Pressure in the system will be monitored with an accurate test gauge upstream of the filter face. The various corrections for density and flow conditions are shown in Table 4. The dimensions and flow rates for this system were arrived at by assuming that the filter media would be operated at its most commonly used velocity when employed for personnal protection and containment operations, i.e. 4.85 fpm (2.46 cm/sec). It was desired to work with a filter diameter of 1 in. or greater and yet be conservative in the quantity of gas consumed. The final inside diameter of the system was fixed at 1.125 inches and the desired velocity of 2.46 cm/sec is achieved for the flow rate of 1 lpm (at pressure) (Table 4).

The aerosol generator will consist of a series of up to eight half millimeter nichrome wires inserted in the apparatus shown in Figure 5. An additional pair of output leads will be installed in the end cap for the insertion of a thermocouple welded directly to one of the wires for constant temperature monitoring.[1] A half inch thick glass window is provided on the side of the aerosol generator section so that the condition of the wires may be observed.

The up- and downstream sampling points are identical in construction (Figure 6). The sampling method will be via point to plane electrostatic precipitation directly on a carbon-coated electron microscope grid.[4] Four radial holes have been bored

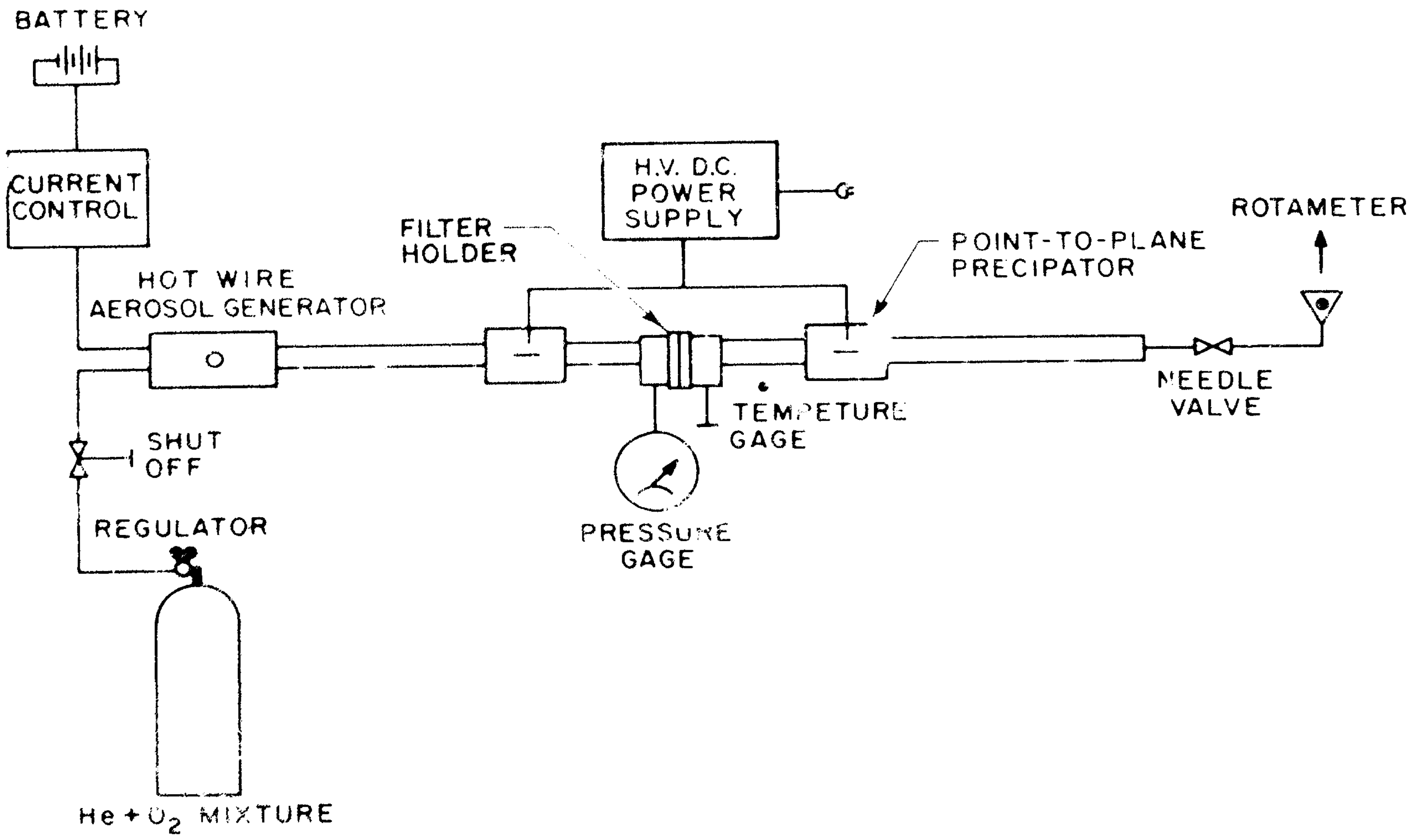

FIG. 4 SCHEMATIC DIAGRAM OF HIGH PRESSURE FILTRATION TEST APARATUS

Table 4. Selected Operating Conditions for High Pressure Filtration Experiment*

Pressure psia	Pressure atm.	Density @ Pressure g/l	Density @ 14.7 psia g/l	Flow @ Pressure - lpm	Flow @ 14.7 psia - lpm
50	3.4	0.809	0.237	1.0	3.4
100	6.8	1.374	0.200	1.0	6.8
300	20.4	3.633	0.177	1.0	20.4
500	34.0	6.091	0.17	1.0	34.0

*V = 2.46 cm/sec (4.85 fpm)

He + 160 mm Hg PO_2 = Total Pressure

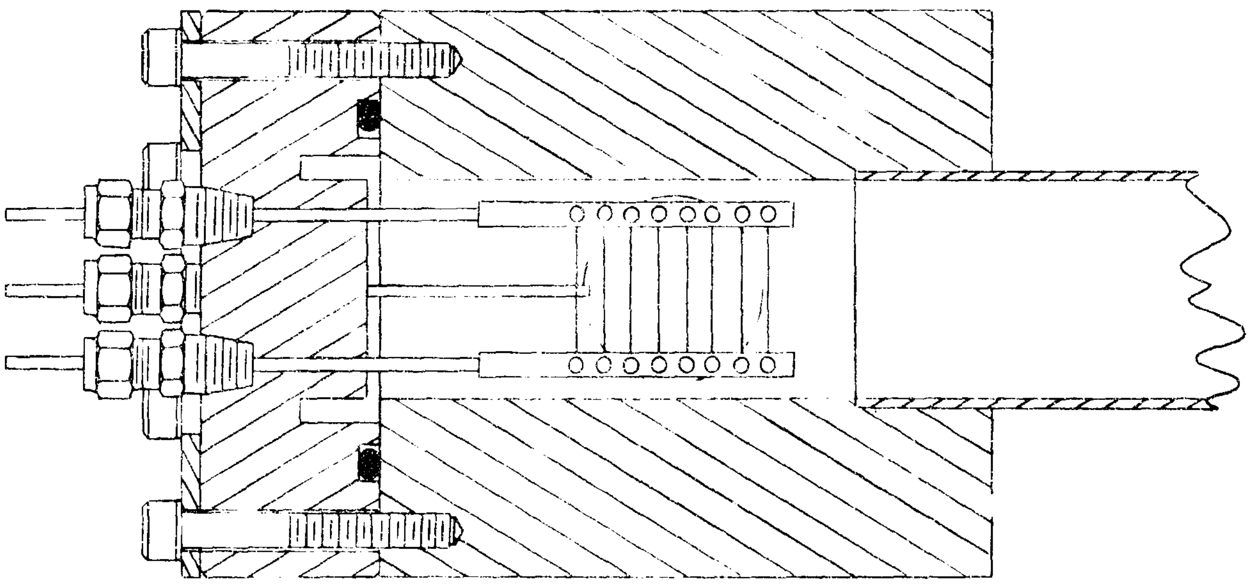

Figure 5. Sectional View of Hot-Wire Aerosol Generator.

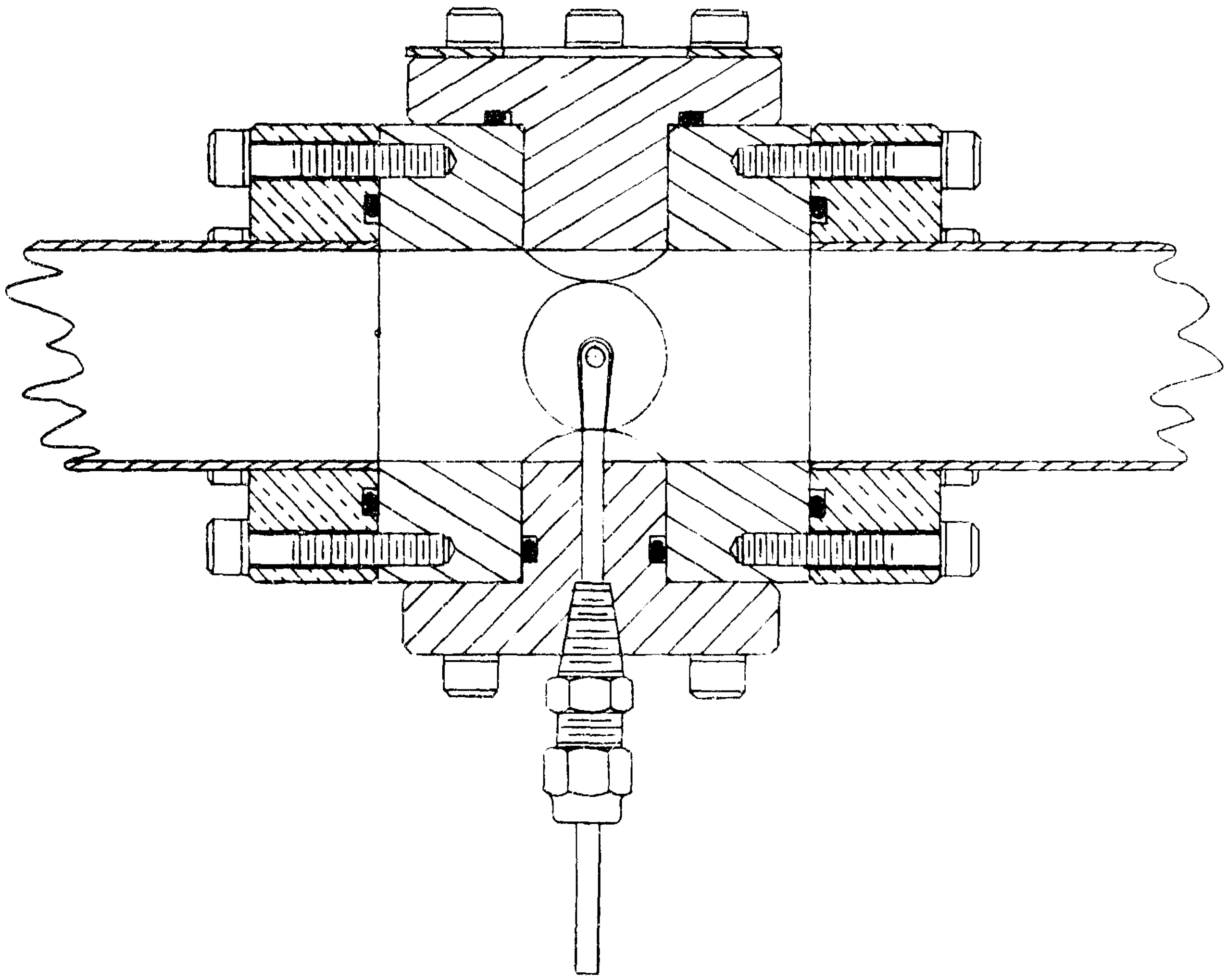

Figure 6. Sectional View of Up- and Downstream Sampling Apparatus.

in the faces of a brass block. Two of these holes contain phenolic plugs mounting the precipitator elements. The electron microscope grid is contained in a beryllium-copper, spring loaded cassette which presents a thin edge profile to the airstream creating a minimum disturbance. The opposite electrode is a fine piece of platium wire. The remaining two radial holes in the block contain clear plastic plugs which serve as windows to permit observation of the condition of the corona discharge. The block has been line-bored so that all four plugs present no disturbance to the air-stream through this section.

The filter holder section consists of two flanges with provision for a backer screen and over-lapping gasket (Figure 7). The over-lapping gasket technique is one which has proved highly successful in the past under a wide variety of conditions.(5) The backer screen will consist of an electro-deposited 60 mesh nickel media.

At the present time the apparatus described above has been completed and leak tested on helium to 600 psia. The remaining details of the experimental protocol will be stipulated prior to the inception of testing.

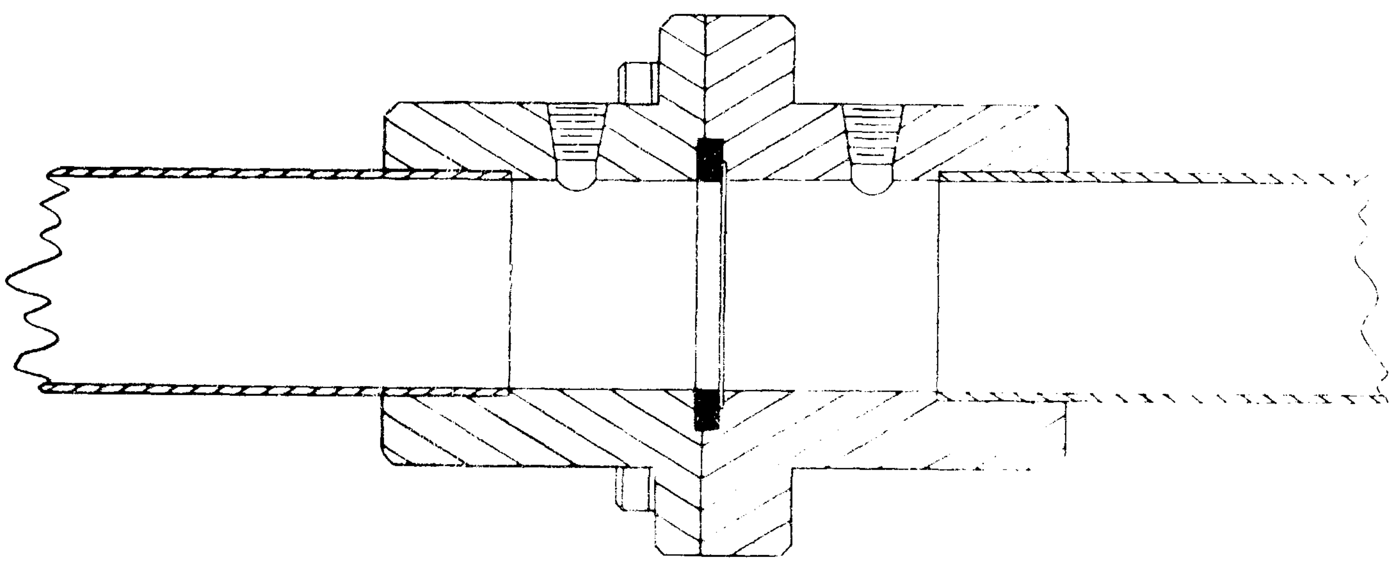

Figure 7. Sectional View of Filter Holder.

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2. Gussman, R.A.: Aerosol Behavior in High Pressure Environments. Rep. No. 1770, Bolt Beranek and Newman Inc., Cambridge, Mass. (Performed under Contract No. N00014-68-C-0271, Dept. of the Navy, Office of Naval Research, Washington, D.C.), 28 Feb. 1969.

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4. Billings, C.E. and L. Silverman: Aerosol Sampling for Electron Microscopy. APCA J., Vol. 12, No. 12, pp. 586-590 (Dec. 1962).

5. Gussman, R.A., R. Dennis and L. Silverman: Notes on the Design and Leak-testing of Sampling Filter Holders. AIHA J., Vol. 23, No. 6, pp. 480-481 (Nov-Dec. 1962).

APPENDIX I: ANNOTATED BIBLIOGRAPHY

BOYLAN, L.: Soviet-Bloc Submersible Development. MTS Journal, Vol. 3, No. 2, pp. 21-44 (March 1969).

This is the first of three articles discussing the history, state of the art, and future development of Soviet-bloc submersible research. This article relates the 45-year history of deep submersible development starting with the founding of the Soviet salvage organization, EPRON, and the construction of the Danilenko diving chamber. Included in this paper are physical descriptions and the missions of all the Soviet-bloc submersibles built since 1923. There are photographs and/or sketches of each device. The author comments that the past history of Soviet-bloc submersible development is not very impressive but he adds that the forthcoming articles which include discussions of the habitat and sealab programs improves the Eastern European involvement.

COX, T.L.: Safety in the Cachalot Saturation Diving System Operations. J. Hydronautics, Vol. 2, No. 4, pp. 187-191 (Oct. 1968).

The Cachalot Saturation Diving system has proved itself much safer than normal deep sea diving; however, the saturated diver must be kept under pressure. A sudden return to one atmosphere of pressure would be fatal. This paper treats, (1) the handling of the saturated diver living in a pressurized chamber at the surface, (2) transferring from there to the underwater work site, and (3) working in the hostile underwater environment. Six divers at a time live in a 26-ft-long, 7-ft-diam chamber. Methods for control of oxygen and inert gas partial pressures, heat, humidity, and contaminants are discussed. Two divers leave the main chamber and enter a diving bell which takes them underwater to the work site. This bell must be handled so as not to endanger the lives of the divers. We must, however, achieve maximum underwater work hours. Problems of handling the bell in rough weather and protecting the vital supply, communication, and monitoring lines are discussed. Divers exit from the bell through a hatch in the bottom, but remain connected to it by 100-ft umbilical lines. In case of any emergency, the bell provides a nearby haven for safety. (author's abstract)

HAMREN, F.E., Jr.: Makai Range Habitat Readied. UST, p. 46, (Feb. 1969).

The Habitat II is described as the first transportable undersea habitat capable of supporting four men for 20 days at depths down to 580 feet. It is being built by Pittsburgh-Des Moines Steel Co. for undersea research by Makai Range Inc. It can be fully outfitted, pressurized and depressurized at dock-side and towed to its offshore site. There is a full description of the facilities aboard Habitat II which include a 30 inch emergency hatch on each of the two cylindrical sections which, together with a central entry sphere, comprise the system. A sketch shows the locations of the facilities available.

KINNE, O. and S. Ruff: Manned Underwater Laboratory in the North Sea. NASA Rpt. No. TT-F-11,785, National Aeronautics and Space Administration, Washington, D.C. (June 1969).

The design of the projected underwater laboratory (UWL) at Helgoland is briefly described. Provisions for the maintenance and medical surveillance of the laboratory personnel are indicated. The future research program, which consists of a medical, a psychological and a marine biology research program, is outlined. (authors' abstract)

KOTTLER, C.: Underwater Systems within the Scientific, Technological, and Economic Framework. J. Hydronautics, Vol. 3, No. 1, pp. 2-11, (Jan 1969).

This paper presents the economic and technological framework within which advanced underwater systems will fit. Many companies and governmental agencies are continuing research into a large number of areas directly or indirectly connected with oceanographic activities. Environmental analysis is yielding better long range predictions as well as some control. Mathematical models with computer assistance provide methods for mission and system analysis. In addition, new subsystems (e.g., nuclear power, scuba, dynamic positioning, etc.), and new or improved materials are extending vehicle system capabilities by orders of magnitude, thereby permitting missions only dreamed of before.

Much needed oceanographic and weather data for analysis of the dynamics of oceanographic processes is possible using a system of instrumented buoys. Military and commercial operations would find environmental analysis extremely valuable.

QUINN, A.: Project Tektite 1 - Four-man Underwater Laboratory. UST, pp. 48-49, (Feb. 1969).

This article discusses the coming operation Tektite I sponsored by the Navy, NASA, Department of the Interior and General Electric. It will take place at a depth of 50 ft. at Great Lameshur Bay, Virgin Islands National Park, St. John Island. Four men will conduct extensive marine science studies on the ocean floor and evaluate man's psychological and physiological reactions to a long term mission, (60 days), under saturated diving conditions.

SENGEYEV, S.: Sadko, Guest of Leningrad. Moscow, Szvestiya, Russia, 15 Nov. 1967.

This article is a narrative account by the author of the dive of the Russian "submarine house" Sadko-2 to a depth of 25 meters in the Black Sea with two men aboard for 10 days. There is a brief description of the living accommodations aboard. The experiments performed by the men are described as 'broad' but there is only reference to investigation of the layer of discontinuity and an underwater current study.

APPENDIX II: SYMBOLS

This list of symbols pertains to the project as a whole and not simply to this report. Therefore, symbols may be listed herein which are not used in this specific report.

A = a numerical factor having a value of approximately unity

A_o = first Cunningham correction coefficient = 1.257

B = second Cunningham correction coefficient = 0.400, mobility of the aerosol particles

C = third Cunningham correction coefficient 1.10, in filtration, a numerical factor of 0.5 to 0.75

C_D = drag coefficient

D = diffusion coefficient

D_i = probability of deposition due to diffusion

E = collecting field strength, efficiency of intact filter, voltage

E_D = diffusional filtration efficiency

E_G = gravitational filtration efficiency

E_I = inertial filtration efficiency

E_j = filtration efficiency due to all mechanisms (j = ERIGM Qq)

E_M = molecular filtration efficiency

E_o = charging field strength

E_{Qq} = electrostatic filtration efficiency (Also: E_{oq}, only fiber is charged; E_{Qo}, only aerosol is charged.)

E_R = direct interception filtration efficiency

$E\beta_j$ = E_j and includes consideration of the interference effect

F = drag on particle

I = current, probability of inertial deposition

I_d = collision intergral

K = agglomeration coefficient

$K_{1,2,3}$ = thermal conductivity

M = collection efficiency, molecular weight

N_D = gravational filtration parameter

N_I = inertial filtration parameter

N_M = molecular filtration parameter

N_o = ion concentration

N_{Qq} = electrostatic filtration parameter

N_R = direct interception filtration parameter

P = pressure in atmospheres

P_c = critical pressure

P_e = Peclet number

P_i = impaction parameter

P_{pc} = psuedo critical pressure

R = radius, gas constant

R_1 = radius of discharge electrode

R_2 = radius of collecting electrode

R_e = Reynolds number

S = ratio of particulate sphere of influence to particle radius, saturation, probability of deposition due to sedimentation

Stk. = Stokes number

T = absolute temperature

T_c = critical temperature

T_d = droplet temperature

T_{pc} = pusedo critical temperature

U_o = velocity of particle (re: mobility, B)

V = gas velocity

V' = applied potential

V_L = molecular volume

Y = mole fraction

Z = electric mobility of ions

Z_2 = electric mobility of O_2 ions

Z_3 = electric mobility of He ions

Z_r = reduced electric mobility of ions

$\bar{c}$ = R.M.S. velocity

d = particle diameter (in filtration as d_p)

d_f = fiber diameter

e = electronic charge

f = fraction

g = gravitational acceleration

h = height

i = current per unit length of electrode

k = Boltzmann's constant, an integer 1, 2, 3, ..., etc.

m = ion mass, droplet mass

n = number concentration of particles, number of electronic charges, e

n_o = initial number concentration of particles

n_s = saturation charge

p = a factor (re: electrification), droplet vapor pressure

p_t = liquid vapor pressure

q = charge acquired in time, t

r = radial distance from electrode centerline

r_{12} = collision diameter

s = fraction of molecules reflected diffusely

t = time

u = drift velocity of particles

v = sedimentation velocity

α = evaporation (condensation) coefficient

β = f(s) (re: slip correction), volume fraction of fibers

γ = 0.499 as extracted from the current expression for λ, surface tension

Δ = vapor shell thickness

δ = 1 for specular reflections of the molecule from a particle but generally $\delta = (1 + \pi s/8)$ (re: slip correction), saturation

ε = dielectric constant

ε_o = dielectric constant of a vacuum. 8.85434×10^{6} amp-sec/volt-cm

η = viscosity of the fluid medium

θ = integer

λ = mean free path of gas molecules

μ = micron

$\nu = (RT/2\pi M)$

ρ = particulate density

ρ_L = liquid density

ρ' = gas density

τ = relaxation time, mean passage time of particles

$\chi = \frac{2\lambda}{d}$, the Knudsen number

ψ' = angle of inclination of a tube with the horizontal

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13. ABSTRACT

The second year of a study has been completed whose main purpose is to elucidate hazards to personnel arising from aerosols in high pressure helium-oxygen atmospheres. This year's efforts included: experimental studies on the generation of aerosols in the high pressure environment, pulmonary deposition modeling, theoretical filter efficiency calculations, and the construction of a high pressure filtration efficiency test apparatus. The first two topics listed are described separately in a previous special report.

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